Neuropsychological and Stress Evaluation of a Residential Mercury Exposure

Nancy Fiedler, Iris Udasin, Michael Gochfeld, Gail Buckler, Kathie Kelly-McNeil, and Howard Kipen

UMDNJ-Robert Wood Johnson Medical School, Piscataway, New Jersey 08855 USA

Residents of a former factory building converted to apartments were exposed to mercury over a 2-year period. The neurobehavioral and emotional health effects of this exposure and subsequent evacuation are presented. Urine mercury levels were measured before (urine1) and 3–10 weeks after evacuation (urine2) of the building, when neurobehavioral and psychological measures were also completed. Performance on neurobehavioral and psychologic measures were compared between subjects above and below the median for urine1 (≥19 µg/g creatinine) and were correlated with urine1 mercury levels. The high urine mercury group made more errors on a test of fine motor function and 84% of the residents reported clinically significant elevations in somatic and psychologic symptoms. Although subclinical tremor from mercury exposure may have affected subtle hand–eye coordination, other tests of motor function were not affected. Therefore, the observation of reduced hand–eye coordination may be due to chance. Significant levels of psychosocial stress were more closely associated with the evacuation necessitated by mercury exposure rather than a direct effect of mercury exposure. *Key words*: environmental exposure, mercury, neuropsychological, stress, urine mercury. *Environ Health Perspect* 107:343–347 (1999). [Online 24 March 1999]

http://ehpnet1.niehs.nih.gov/docs/1999/107p343-347fiedler/abstract.html

The acute and chronic behavioral effects of mercury in humans have been documented in cases of acute poisoning (*1–3*) and epidemiologic studies of occupational exposures (*4,5*). Adverse neurobehavioral effects of inorganic mercury include reduced cognitive functions (e.g., memory and concentration) and emotional disturbances such as depression, irritability, emotional lability, and fatigue (*5,6*). Environmental exposures to mercury occur through fish consumption, waste incineration, energy production, and the widespread use of dental amalgams, although the health consequences of these exposures are unclear (*7–9*).

Nonoccupational community exposures to neurotoxicants are often unexpected and traumatic (*10,11*). Therefore, the direct neurologic and neurobehavioral effects of exposure may be accompanied by symptoms of trauma and stress. The purpose of the present study was to evaluate neurobehavioral performance and psychological symptoms in response to an elemental mercury exposure that occurred in a community and resulted in the evacuation of residents from their contaminated homes.

A five-story factory building, used to manufacture mercury vapor lamps in the 1930s, was converted to condominium apartments by an artists' cooperative and was occupied in 1994–1995 by the artists and their families. A majority of the occupants used their apartments as both living and working quarters and at least one family member was in the building full-time for approximately 2 years. When the mercury contamination was discovered and reported, average air mercury levels ranged from 5 µg/m^3 in adult breathing zones with a peak value of 888 µg/m^3 over visible pools of liquid mercury on the floor (*12*). Air levels in some living quarters exceeded the Occupational Safety and Health Administration permissible exposure limit of 50 µg/m^3. Prior to evacuation, 90% (n = 26 of 29) of the residents, including children, had urine mercury levels, normalized to a specific gravity of 1.024, of >20 µg/l (*13*). Thus, 90% of the residents exceeded the upper limit for an unexposed population. The residents were evacuated to temporary housing paid for by the EPA. After extensive assessment documented the pervasive distribution of mercury, the building was condemned.

Numerous studies from the occupational literature report symptoms and/or reduction in neurobehavioral performance with chronic exposures to mercury vapor (*14–21*). Studies vary in the methods used to assess neurologic function and in the duration and concentration of exposures. Therefore, results are not always consistent. Objective neurobehavioral deficits are reliably documented at higher concentrations of urine mercury (e.g., 200–450 µg/l) (*22,23*), but variable results occur at lower concentrations (e.g., 16–56 µg/l), with some studies reporting emotional disturbances but no neurobehavioral deficits (*14,16,17*) while others document significant neurobehavioral findings (*18–21*).

In the present study, urine mercury levels were measured both before (urine1) and after (urine2) termination of exposure. Computerized and traditional tests of neurobehavioral function, psychological and somatic symptom reports, and the impact of self-identified stressors were measured as indicators of health effects following evacuation of the dwellings. Medical history and exams were also performed. This study reports on the neurobehavioral effects of an uncommon and unexpected residential exposure, which for many of the residents occurred on a 24-hr basis.

Materials and Methods

Subjects. The 37 residents at risk for mercury exposure in the converted building were referred for evaluation by the Agency for Toxic Substances and Disease Registry (ATSDR) through the Association of Occupational and Environmental Clinics. Evaluations were performed at the Clinical Center of the Environmental and Occupational Health Sciences Institute (EOHSI; Piscataway, NJ). Thirteen male and 14 female adults with an average age of 41.3 years [standard deviation (SD) 7.7; range, 25–55) and average education of 17.2 years (SD 1.8; range, 12–20) presented for a medical evaluation and neuropsychological screening battery. The six children (ages 9 months–8 years) were evaluated separately by the Department of Pediatrics of the University of Medicine and Dentistry of New Jersey–Robert Wood Johnson Medical School. Four residents (4 of 37; 11%) were not evaluated because of scheduling conflicts.

The protocol for this medical evaluation was developed in collaboration with the ATSDR and the Clinical Center of EOHSI and was offered free of charge to the residents after their building was declared uninhabitable. Of the 27 adults and 6 children who were evaluated, one female elected not to complete the neurobehavioral testi ng and one male was excluded from neurobehavioral test analyses because of a preexisting neuropathy. Chinese was the first language for two additional residents; therefore, they did not complete the language-based performance

Address correspondence to N. Fiedler, UMDNJ-Robert Wood Johnson Medical School, 170 Frelinghuysen Road, Piscataway, NJ 08855 USA.

We thank all the agencies and related staff for their consultation, assistance, and financial support. Drs. Bernard Goldstein and Pam Tucker provided valuable comments and information. We also very much appreciate the participation of the apartment residents. This project was funded by the Agency for Toxic Substances and Disease Registry.

Received 11 December 1998; accepted 8 February 1999.

tests (i.e., California Verbal Learning, Paired Associates, Vocabulary) and mood questionnaires [Symptom Checklist 90, Revised (SCL-90-R), Impact of Events Scale (IES)].

The ATSDR, the New Jersey Department of Health (NJDOH; Trenton, NJ), the EPA, the Hoboken Board of Health (Hoboken, NJ), and the Hudson Regional Health Commission (Harrison, NJ) investigated the site. Preliminary environmental and exposure results have been published (*12*), including air monitoring of the building conducted by both private consultants and the NJDOH, and spot urine samples obtained 27 December 1995 and analyzed for mercury by the NJDOH laboratory (*13*). Because of the high levels of mercury detected in the air and in residents' urine (up to 102 µg/l, normalized to a specific gravity of 1.024), the building was evacuated, all residents were relocated in January 1996, and the ATSDR referred the residents for medical examinations at the EOHSI.

Medical evaluation. These evaluations were performed in January–March 1996 (3–10 weeks postevacuation). Each subject was asked to review and sign an informed consent. The evaluation consisted of review of medical, occupational, and environmental history by a board-certified occupational physician and a targeted physical examination with special attention to blood pressure, respiratory, skin, oral cavities, and nervous systems. Blood chemistry panels, complete blood count, urinalysis, and urine creatinine were performed by a commercial clinical laboratory. On the day of the examination, a spot urine sample (urine2) was analyzed for mercury and creatinine by the NJDOH–Environmental and Chemical Laboratory Services. Specimens were collected in metal-free acid-washed plastic containers, refrigerated, and sent by courier to the NJDOH laboratory with field blanks (deionized water). Analysis was performed by cold vapor technique. Sample runs included calibration curves, spiked samples (recoveries >85%), and 10% duplicates. The interval between urine1 and urine2 ranged from 5 to 11 weeks. All urine mercury levels were corrected for creatinine (C) to control for variable urine dilution.

Neuropsychological evaluation. Based on published studies of the neuropsychological effects of mercury exposure, tests reflective of the following functions were chosen: tremor, peripheral neuropathy, psychomotor coordination (speed), verbal learning and memory, basic skills or premorbid ability, and mood (*4*). To assess psychological distress, the IES, the SCL-90-R, and the Neurobehavioral Evaluation System 2 (NES2) mood scales were administered (Table 1). The tests for the neurobehavioral assessment of the children were selected based on the age of the child and included the following standardized tests: Bayley Scales of Infant Development (*24*); Vineland Adaptive Behavior Scales (*25*); Peabody Picture Vocabulary Test (*26*); Purdue Pegboard (*27*); story memory from the Wide Range Assessment of Memory and Learning (*28*); Finger Tapping (*29*); Visual Motor Integration (*30*); Personality Inventory for Children (*31*); Expressive One-Word Picture Vocabulary Test, Revised (*32*); vocabulary, matrices, and definitions of the Kaufman Brief Intelligence Test (*33*); matrix analogies of the Kaufman Assessment Battery (*34*); the Wechsler Intelligence Scale for Children (*35*); and Verbal Cancellation (*36*).

Statistical analyses. Because of the small sample size and the non-normality of the data sets, nonparametric data analytic methods were used. Wilcoxon rank sum tests were used to compare groups with high and low urine mercury level and Kendall Tau correlations were performed to assess the relationship between urine mercury and the dependent measures. Because of the small sample size and consequent lack of statistical power, significance levels of 0.10 or less are reported. For the purpose of statistical analysis, adult subjects with urine1 above the median value of 19.4 µg/g creatinine (>19) were categorized as high exposure (n = 7 women, 3 men), whereas those <19 were classified as low exposure (n = 3 women, 6 men). Urine1 was used because it reflected levels for subjects while exposures were ongoing. Therefore, the performance of 19 adult residents, classified as high or low exposure, were compared. Eight of the 27 subjects were not classified for the following reasons: one was excluded for neuropathy; one did not complete neurobehavioral tests; and six had no urine1 data.

Results

Medical evaluation. Occupational, exposure, and medical histories were obtained from each adult subject. Of the 27 adults evaluated, there were 14 self-identified artists, 3 engineers, 3 computer specialists, 2 musicians, 2 salespeople, 2 construction contractors, and 1 financial trader. Seventeen considered themselves occupationally exposed to solvents including oil-based paints, paint thinners, and glues; 10 individuals did not have significant solvent exposure by history.

The medical history identified two subjects with a history of disease that included neurologic findings and predated their exposure to mercury, (i.e., connective tissue disorder and vascular disease). One of these refused neurobehavioral testing and results for the other were excluded from the statistical analyses. However, these two subjects were among those with the highest urine1 mercury levels (i.e., 49.7 and 67.0 µg/g creatinine, respectively). Other pertinent results of the medical evaluation were as follows: history of multiple miscarriages (n = 1); difficulty conceiving (n = 1); pregnant at the time of evaluation (n = 1); nursing at the time of the evaluation (n = 1). During the interview by the occupational physician, all subjects denied current or past substance abuse or other exposure to mercury.

On physical examination, four subjects with abnormal skin conditions (one with psoriasis, three with eczema) were identified. One subject reported a hand tremor, which could not be seen on examination. One subject had a tongue tremor. Otherwise, physical findings were unremarkable.

For adults, mercury concentration (micrograms per gram creatinine) in urine1 readings (n = 19; mean ± SD, 22.4 ± 14.5; range, 3.1–52.6) were not significantly different from urine2 readings (n = 23; mean ± SD, 21.8 ± 21.6; range, 0–94.1) (one adult had no urine2 data and one reading was not used in analyses because of high dilution) and the two readings were significantly correlated (urine1 × urine2: r = 0.57; p<0.001).

Upon individual inspection, the urine of two of the children was unusually diluted at urine2, which resulted in anomalous readings. Therefore, these children were excluded from mean values (urine1, n = 4; mean ± SD, 61.1 ± 49.2; range, 23.1–133.0; urine2, n = 4; mean ± SD, 62.4 ± 25.5; range, 38.6–85.3).

Neurobehavioral performance and psychological distress—high versus low urine mercury. The high (n = 10) versus low (n = 9) exposure groups did not differ in age or education (high exposure: age mean ± SD, 40.6 ± 9.0; range, 25–55; education mean ± SD, 17.7 ± 1.4; range, 16–20; low exposure: age mean ± SD, 37.8 ± 6.3; range, 25–45; education mean ± SD, 17.3 ± 1.6; range, 15–20). Subject groups also did not differ on vocabulary scores (high exposure: mean ± SD, 20.1 ± 4.9; range, 10–25; low exposure: mean ± SD, 22.8 ± 1.7; range, 19–25). However, there tended to be more women (n = 7) than men (n = 3) in the high-exposure group and more men (n = 6) than women (n = 3) in the low-exposure group (Fisher's exact test p<0.18). This may have been due to the increased time spent by women in the apartments.

Separate Wilcoxon rank sum analyses compared neurobehavioral performance and emotional symptoms of subjects high and low in urine mercury. The high-exposure group committed significantly more errors on the computerized hand–eye fine

Table 1. Adult neuropsychological evaluation

Function and test	Description	Measure	Reference
Motor skills			
Finger Tapping (NES2)	Press a button as many times as possible within a specific interval with preferred, nonpreferred, and then alternating hands	Number of taps	(*37*)
Hand–Eye Coordination (NES2)	Use a joystick to manipulate a steadily moving computer cursor over a sine-wave pattern	Log root mean squared error of two best trials	(*37*)
Grooved Pegboard	Timed test of manipulative dexterity where pegs must be rotated to match a hole before being inserted	Time (sec) for dominant and nondominant hand	(*38*)
Peripheral neuropathy			
Vibration Threshold	Using Vibratron II[a], an ascending protocol is used to measure sensitivity to vibration in first and fifth index finger on dominant and nondominant hands	Mean threshold score	(*39*)
Psychomotor coordination			
Trail Making Test, Part A and B	Timed paper and pencil test in which numbers are connected in sequence as well as shifting between numbers and letters	Time (sec)	(*40*)
Symbol–Digit Substitution (NES2)	Nine symbols and nine digits are paired in a key on the screen and the subject must press the digit on the keyboard corresponding to a test set of the nine symbols presented in scrambled order	Average sec/digit	(*37*)
Simple Reaction Time (NES2)	Test of concentration and visual reaction time where the interstimulus interval is varied randomly to reduce effects of stimulus anticipation	Mean response latency (msec)	(*37*)
Continuous Performance (NES2)	Choice reaction time test administered over 60 trials during a 5-min period	Median reaction time (msec)	(*37*)
Verbal learning and memory			
California Verbal LearningTest	Verbal learning and memory for list of 16 common shopping items	Number of words recalled	(*41*)
Verbal Paired Associates I and II	Eight word pairs are verbally presented then the first word of each pair is given and must be matched with the second word from memory. For delayed recall 30 min later the recall list is read and the associated response for each item is needed	Number of words recalled	(*42*)
Basic skills			
Vocabulary (NES2)	Multiple choice where the subject must select the synonym that matches the presented word	Number of words correct	(*37*)
Standard Progressive Matrices (Sets A–C)	Assesses nonverbal abstract reasoning: each set of 12 items contains a pattern with a part removed and six pictured inserts, one containing the piece to correct the pattern	Total number of errors	(*43*)
Psychological distress			
Mood Scales (NES2)	Similar to Profile of Mood States (*44*), where subjects rate themselves with respect to their feelings over the previous 7 days	Mean scores	(*37*)
SCL-90-R	Ninety-item self-report symptom inventory	T-scores	(*45*)
Impact of Events Scale	Scale of current subjective distress related to a specific event	Raw scores	(*46*)

Abbreviations: NES2, Neurobehavioral Evaluation System 2; SCL-90-R, Symptom Checklist 90, Revised.
[a]Physitemp Instruments, Inc., Clifton, New Jersey.

motor coordination test (high-exposure mean ± SD, 2.3 ± 0.34; range, 1.8–2.9; low-exposure mean ± SD, 2.0 ± 0.15; range, 1.7–2.2; $p<0.05$). No significant differences between the groups were noted on any other measures of neurobehavioral performance or psychological distress listed in Table 1. Because there were gender differences between the groups, the effect of gender on each neurobehavioral variable was compared regardless of exposure status. The only neurobehavioral variable that was significantly different between men and women was errors in hand–eye coordination. Regardless of exposure, women made significantly more errors than men (female mean ± SD, 2.3 ± 0.29; range, 1.9–2.9; male mean ± SD, 2.0 ± 0.16; range, 1.7–2.2; $p<0.007$). Despite the small number of subjects, Wilcoxon rank sum analyses were conducted separately for each gender and exposure status. Women in the high-exposure group tended to make more errors on hand–eye coordination than women in the low-exposure group (female high-exposure mean ± SD, 2.4 ± 0.33; range, 1.9–2.9; female low-exposure mean ± SD, 2.1 ± 0.04; range, 2.09–2.14; $p<0.11$). This difference was not observed for men (male high-exposure mean ± SD, 2.0 ± 0.19; range, 1.8–2.2; male low-exposure mean ± SD, 1.9 ± 0.16; range, 1.7–2.2, $p<0.90$). It should also be noted that for the six subjects who did not have urinel values, their performance on the hand–eye coordination task spanned the range of performance while the subject removed from the analysis because of neuropathy was in the poorest quartile of performance and had a high urinel (67 µg/g creatinine).

Neurobehavioral, affect, and mood scores for all subjects were correlated with urinel. The correlation between urinel and errors on hand–eye coordination was significant ($r = 0.37$ $p<0.03$), whereas no other significant correlations were observed.

Psychological distress results. Although no statistically significant differences in measures of psychological distress were observed between those high and low in urine mercury, comparison of group means to normative standards available for the IES and the SCL-90-R was also conducted to determine the clinical significance of psychological distress for all subjects ($n = 25$) except those whose first language was Chinese ($n = 2$). For the IES, subjects had a level of total stress, intrusive and avoidant thoughts, and behaviors consistent with stress disorder patients seeking outpatient services (*46*). Most individuals reported trauma of leaving and losing their homes ($n = 14$). Two subjects cited medical concerns related to mercury poisoning, and two subjects were concerned about the stress of dealing with the financial, political, and legal problems. Seven subjects did not list a specific trauma.

For the SCL-90-R, mean T-scores for the group were within the clinically positive range (i.e., >63) for the global severity index and the obsessive–compulsive, depression, anxiety, hostility, and paranoid ideation scales. For an individual, a global severity index T-score >63 or two or more scale T-scores >63 is considered indicative of significant psychological distress (*45*). Twenty-one of 25 subjects (84%) met this criterion.

Pediatric neurobehavioral evaluation. The six children were evaluated clinically by pediatricians and pediatric neurologists. Because of the small number of exposed children and the wide age range, statistical comparisons could not be made. However, relative to age-adjusted normative values, no clinically significant deficits were found for any of the children. None of the six children showed evidence of gross neuropathologic impairment. Subtle neurodevelopmental effects, however, can neither be identified nor ruled out in this evaluation.

Discussion

Residential exposure is a relatively rare event (*47*). The present study is unique in documenting moderately high residential exposures to mercury leading to urine mercury levels comparable to low-level occupational exposures (*14,18*). The group is unusual because more women than men were among the highest exposed, reflecting the fact that the female artists both lived and worked in the apartments. The neurobehavioral effects of both elemental and organic mercury are well established (*48*). Reduced performance on a task dependent on accurate fine motor coordination was observed among those subjects with higher urine mercury.

Although these results are consistent with findings from other investigations of occupational exposures [e.g., Ngim et al. (*19*), Netterstrom et al. (*21*), and Williamson et al. (*49*)], the present study cannot exclude factors other than mercury exposure to explain the results. First, several tests of motor function were administered with only one showing a significant difference and that difference was potentially confounded by gender. However, with a relatively small number, a difference remained after controlling for gender (p<0.11). Moreover, on average, women perform better than men on tests of fine motor function (*50*). Therefore, the present finding of poorer performance among women in the sample is not consistent with the literature on other tests of fine motor function. In addition, an argument can be made that of the motor tests given, hand–eye coordination may be most sensitive to tremor. That is, hand–eye coordination requires fine movements with a joystick and detects errors on departures from a line on a video display. These task requirements may be more sensitive than the relatively gross requirements of placing pegs in holes [Grooved Pegboard (*38*)] or Finger Tapping (*37*). Moreover, fine subclinical tremor is not the same as peripheral neuropathy that was assessed with the vibratron. Despite these logical arguments, it is acknowledged that the present results may be a function of chance rather than of mercury exposure.

The present study also documented a significant level of psychological distress among subjects, 84% of whom reported a clinically diagnostic level of distress. Overall, the group reported levels of avoidant and intrusive symptoms similar to patients seeking services at a stress disorder clinic (*46*). Many of the symptoms reported (e.g., irritability, fatigue) may result from exposure to neurotoxicants such as mercury as well as from stress. Although causality cannot be inferred from the present study design, several factors suggest that the psychological symptoms were secondary to the discovery of contamination and subsequent evacuation rather than a direct neurotoxic effect of mercury. First, no significant differences in psychological measures were noted between the high and low urine mercury groups and no significant correlations were observed between urine mercury and measures of psychological distress on the SCL-90-R, Mood Scales, or IES. Second, when subjects were asked to record the traumatic event that they associated with their symptoms of avoidance or intrusion on the IES (*46*), the majority of subjects reported the trauma of being forced to leave their homes, workspaces, and possessions rather than mercury exposure per se. Thus, with few exceptions, the loss of homes or investments was considered highly stressful.

A growing literature documents that both environmental and occupational exposures to chemicals have been associated with symptoms such as headaches, anxiety, depression, and fatigue (*51–53*). Spurgeon et al. (*54*) reviewed this literature and suggested a model that included not only the physical causes of these symptoms but also incorporated a sample of the psychological variables/stressors that contribute to symptom reports often attributed to a toxin. Health effects documented in the present study are examples of the complex interaction between chemical exposure and psychological stressors (e.g., loss of home) that occurred in response to that exposure.

The conversion of former industrial/commercial facilities to artists' studios and residences has been part of urban revival in several large cities including New York City and Jersey City, New Jersey. In Hoboken, the artists' cooperative was led to believe that they were purchasing a former tool and die factory; information on former mercury vapor lamp production was withheld from them. Over a 1- to 2-year period, the residents converted the building into about 16 large (approximately 4,000 ft^2) apartments. They personally designed the layout and performed most of the carpentry and finishing work themselves. Unlike most apartment dwellers, these residents had huge emotional, time, and monetary investments in these apartments. Whereas their spouses went elsewhere to work, the artists both lived and worked full-time in the building.

Occupational health professionals are generally trained to evaluate health effects of exposure based on dose–response toxicology of a chemical. The present study demonstrates how the psychological stressors that accompany the exposure may have significant health effects of their own. Future studies to understand both the direct health risks of chemical and physical agents and indirect health risks due to psychological stressors are necessary to design better strategies for maximum reduction of persistent health effects after unintended exposure. To offer pragmatic solutions, these studies should incorporate not only toxic health risks from chemical exposure but the symptomatic psychological health consequences of regulatory and environmental interventions.

Conclusion

In the summer of 1998, after 30 months of living in temporary EPA-subsidized housing and paying their mortgages on uninhabitable apartments, the Hoboken artists began receiving compensation from the federal government for their lost real estate. The artists continue to report significant psychosocial stress.

The impact of exposure to toxic chemicals extends beyond the direct organ toxicity and even beyond the future health risks that can only be estimated, and includes significant impacts on psychosocial well-being and quality of life.

References and Notes

1. Vroom RQ, Greer M. Mercury vapour intoxication. Brain 95:305–318 (1972).
2. Bluhm RE, Bobbitt RG, Welch LW, Wood AJJ, Bonfiglio JF, Sarzen C, Heath AJ, Branch RA. Elemental mercury vapour toxicity, treatment, and prognosis after acute, intensive exposure in chloralkali plant workers. Part I: history, neuropsychological findings and chelator effects. Hum Exp Toxicol 11:201–210 (1992).
3. Snodgrass W, Sullivan JB, Rumack BH, Hashimoto C. Mercury poisoning from home gold ore processing. Use of penicillamine and dimercaprol. J Am Med Assoc 246:1929–1931 (1981).
4. ATSDR. Toxicologic Profile for Mercury. Atlanta, GA:Agency for Toxic Substances and Disease Registry, 1994.
5. Ratcliffe HE, Swanson GM. Human exposure to

mercury: a critical assessment of the evidence of adverse health effects. J Toxicol Environ Health 49:221–270 (1996).
6. Hanninen H. Behavior effects of occupational exposure to mercury and lead. Acta Neurol Scand 66:167–175 (1982).
7. Silberud RL. The relationship between mercury from dental amalgam and mental health. Am J Psychother 43:575–587 (1989).
8. Herrstrom P, Holmen A, Karlsson A, Raihle G, Schutz A, Hogstedt B. Immune factors, dental amalgam, and low-dose exposure to mercury in Swedish adolescents. Arch Environ Health 49:160–164 (1994).
9. Herrstrom P, Schutz A, Raihle G, Holthuis N, Hogstedt B, Rastam L. Dental amalgam, low-dose exposure to mercury, and urinary proteins in young Swedish men. Arch Environ Health 50:103–107 (1995).
10. Bowler RM, Hartney C. Amnestic disturbance and posttraumatic stress disorder in the aftermath of a chemical release. Arch Clin Neuropsychol 13:455–471 (1998).
11. Solomon SD, Smith EM. Social support and perceived control as moderators of responses to dioxin and flood exposure. In: Individual and Community Responses to Trauma and Disaster: The Structure of Human Chaos (Ursano RJ, McCaughey BG, Fullerton CS, eds). New York:Cambridge University Press, 1994;179–200.
12. CDC. Mercury exposure among residents of a building formerly used for industrial purposes—New Jersey, 1995. MMWR 45:422–424 (1996).
13. Orloff KG, Ulirsch G, Wilder L, Block A, Fagliano J, Pasqualo J. Human exposure to elemental mercury in a contaminated residential building. Arch Environ Health 52:169–172 (1997).
14. Piikivi L, Hanninen H. Subjective symptoms and psychological performance of chlorine-alkali workers. Scand J Work Environ Health 15:69–74 (1989).
15. Ehrenberg RL, Vogt RL, Smith AB, Brondum J, Brightwell WS, Hudson PJ, McManus KP, Hannon WH, Phipps FC. Effects of elemental mercury exposure at a thermometer plant. Am J Ind Med 19:495–507 (1991).
16. Schuckmann F. Study of preclinical changes in workers exposed to inorganic mercury in chloralkali plants. Int Arch Occup Environ Health 44:193–200 (1979).
17. Langworth S, Almkvist O, Soderman E, Wikstrom B-O. Effects of occupational exposure to mercury vapour on the central nervous system. Br J Ind Med 49:545–555 (1992).
18. Piikivi L, Hanninen H, Martelin T, Mantere P. Psychological performance and long-term exposure to mercury vapors. Scand J Work Environ Health 10:35–41 (1984).
19. Ngim CH, Foo SC, Boey KW, Jeyaratnam J. Chronic neurobehavioural effects of elemental mercury in dentists. Br J Ind Med 49:782–790 (1992).
20. Liang Y, Sun R, Chen Z, Li L. Psychological effects of low exposure to mercury vapor: application of a computer-administered neurobehavioral evaluation system. Environ Res 60:320–327 (1993).
21. Netterstrom B, Guldager B, Heeboll J. Acute mercury intoxication examined with coordination ability and tremor. Neurotoxicol Teratol 18:505–509 (1996).
22. Smith PJ, Langolf GD, Goldberg J. Effects of occupational exposure to elemental mercury on short term memory. Br J Ind Med 40:413–419 (1983).
23. Levine SP, Cavender GD, Langolf GD, Albera JW. Elemental mercury exposure: peripheral neurotoxicity. Br J Ind Med 39:136–139 (1982).
24. Bayley N. Bayley Scales of Infant Development. 2nd ed. Odessa, FL:Psychological Assessment Resources, Inc., 1993.
25. Sparrow SS, Balla DA, Cicchetti DV. Vineland Adaptive Behavior Scales. Circle Pines, MN:American Guidance Service, 1984.
26. Dunn LM, Dunn LM. Peabody Picture Vocabulary Test—Revised. Circle Pines, MN:American Guidance Service, 1981.
27. Gardner RA, Broman M. The Purdue pegboard: normative data on 1,334 school children. J Clin Child Psychol 8:156–162 (1979).
28. Sheslow D, Adams W. Wide Range Assessment of Memory and Learning. Wilmington, DE:Jastak Associates, Inc., 1990.
29. Reitan RM. Unpublished data, 1969.
30. Beery KE. The Developmental Test of Visual Motor Integration. Cleveland, OH:Modern Curriculum Press, 1989.
31. Lachar D. Personality Inventory for Children. Los Angeles, CA:Western Psychological Services, 1995.
32. Gardner MF. Expressive One-Word Picture Vocabulary Test—Revised Manual. Novato, CA:Academic Therapy Publications, 1990.
33. Kaufman AS, Kaufman NL. Manual for the Kaufman Brief Intelligence Test. Circle Pines, MN:American Guidance Service, 1990.
34. Kaufman AS, Kaufman NL. K-ABC Administration and Scoring Manual. Circle Pines, MN:American Guidance Service, 1983.
35. Wechsler D. Wechsler Intelligence Scale for Children. 3rd ed. San Antonio, TX:The Psychological Corporation, 1991.
36. Mesulam MM. Principles of Behavioral Neurology. Philadelphia, PA:F.A. Davis, 1985.
37. Letz R, Baker EL. NES2 Neurobehavioral Evaluation System (Version 4.2) User's Manual. Winchester, MA:Neurobehavioral Systems, Inc., 1988.
38. Trites RL. Neuropsychological Test Manual. Ottawa, Ontario, Canada:Royal Ottawa Hospital, 1977.
39. Anger WK, Sizemore OJ. Adult Environmental Neurobehavioral Test Battery (AENTB) Examiner Training Manual. Atlanta, GA/Portland, OR:Agency for Toxic Substances and Disease Registry/Oregon Health Sciences University; 1993.
40. Reitan RM, Wolfson D. The Halstead–Reitan Neuropsychological Test Battery. Tucson, AZ:Neuropsychological Press, 1985.
41. Delis DC, Kramer JH, Kaplan E, Ober BA. California Verbal Learning Test. San Antonio, TX:The Psychological Corporation, 1987.
42. Wechsler D. Wechsler Memory Scale—Revised. San Antonio, TX:The Psychological Corporation, 1987.
43. Raven JD, Court JH, Raven J. Manual for Raven's Progressive Matrices and Vocabulary Scales. Oxford:Oxford Psychologists Press Ltd., 1992.
44. McNair DM, Lorr M, Dropleman LF. EITS Manual—Profile of Mood States. San Diego, CA:Educational and Testing Services, 1971.
45. Derogatis LR. SCL-90-R Administration, Scoring and Procedures Manual II. Towson, MD:Clinical Psychometric Research, 1983.
46. Horowitz M, Wilner N, Alvarez W. Impact of Event Scale: a measure of subjective stress. Psychosom Med 41:209–218 (1979).
47. Taueg C, Sanfilippo DJ, Rowens B, Szejda J, Hesse JL. Acute and chronic poisoning from residential exposures to elemental mercury—Michigan, 1989–1990. Clin Toxicol 30:63–67 (1992).
48. Evans HL, Laties VG, Weiss B. Behavioral effects of mercury and methylmercury. Fed Proc 34:1858–1867 (1975).
49. Williamson AM, Teo RKC, Sanderson J. Occupational mercury exposure and its consequences for behaviour. Int Arch Occup Environ Health 50:273–286 (1982).
50. Lezak MD. Neuropsychological Assessment. New York:Oxford University Press, 1995.
51. Rowland A, Grainger R, Stanwell-Smith R, Hicks N, Hughes A. Water contamination in north Cornwall: a retrospective cohort study into the acute and short-term effects of the aluminum sulphate incident in July 1988. J R Soc Health 110:166–172 (1990).
52. McMillan TM, Freemont AJ, Herxheimer A, Denton J, Taylor AP, Pazianas M, Cummin AR, Eastwood JB. Camelford water poisoning accident: serial neuropsychological assessments and further observation on bone aluminium. Hum Exp Toxicol 12:37–42 (1993).
53. Roht, LH, Vernon SW, Weir FW, Pier SM, Sullivan P, Reed LJ. Community exposure to hazardous waste disposal sites: assessing reporting bias. Am J Epidemiol 122:418–424 (1985).
54. Spurgeon A, Gompertz D, Harrington JM. Modifiers of non-specific symptoms in occupational and environmental syndromes. Occup Environ Med 53:361–366 (1996).